

The KM3NeT project for a Very Large Submarine Neutrino Telescope

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ABSTRACT

The groups presently pursuing neutrino telescope projects in the Mediterranean Sea, ANTARES, NEMO, and NESTOR, have formed the new KM3NeT consortium to study the construction of a cubic kilometre-scale neutrino telescope for the Northern hemisphere. This challenging project will require the installation of thousands of photon detectors with their related electronics and calibration systems several kilometres below the sea level. The realization of this project will provide the scientific community with a very powerful instrument to study many astrophysical objects, including supernova explosions, active galactic nuclei, gamma-ray bursts and possibly also dark matter. The construction of this detector will require the solution of technological problems common to many deep submarine installations, and will help pave the way for other deep-sea research facilities. In April 2008 the KM3NeT consortium has reached the important milestone of the publication of the Conceptual Design Report (CDR) for the KM3NeT telescope. The European Union – funded 3 year Design Study phase has now passed its mid-way point and will culminate in 2009 with the writing of the KM3NeT Technical Design Report (TDR), detailing the most promising technologies and the expected physics performance of the future detector. Concurrent with the publication of the CDR an E-U funded Preparatory Phase began which will lead to the telescope construction. Aspects of the KM3NeT project related to deep-sea infrastructure, deployment and operation are reviewed in this report.

KEYWORDS:

Neutrino telescope, Deep sea infrastructure, Photon detectors

1. INTRODUCTION

The observation of high-energy extraterrestrial neutrinos is likely to be the most promising option to increase our knowledge of very energetic processes in the universe. Neutrinos are elusive, uncharged particles that interact only very weakly with matter. At low energies they are copiously produced in nuclear reactors, while higher energy ‘synthetic’ neutrino beams can be produced at accelerators in the decays of subatomic particles called pions. We therefore expect astrophysical accelerators of cosmic rays to also be sources of high energy neutrinos. The galactic centre, supernova explosions, active galactic nuclei and gamma-ray bursts are likely to be rich neutrino sources. Other more exotic phenomena like dark-matter annihilation could also produce detectable neutrino fluxes.

The history of science has illustrated that when mankind has started to observe the Universe with new kinds of instruments, new and fascinating phenomena have usually appeared.

Present estimates of expected neutrino fluxes from astrophysical objects, when taken together with the very low interaction rate of neutrinos with matter, suggest that unambiguous detection of astrophysical neutrino sources will be possible only through the use of detectors having at least a cubic kilometre of instrumented volume.

Neutrino telescopes must be ‘buried’ under thousands of metres of ice or water to shield them from background generated by much more copious charged cosmic rays. A one cubic kilometre detector is currently under construction in the deep South Pole ice. Another detector of similar size is needed in the Northern hemisphere to complement the Southern telescope and achieve full sky coverage [1,2].

The Mediterranean Sea is an ideal place for such a telescope since it has deep enough trenches and generally better deep sea conditions (current speed and water transparency) than in the deep oceans. Nevertheless the construction and deployment of a detector at 2-5 km depth is a scientific and technological challenge. All the detector elements must resist a pressure of several hundred

atmospheres, and survive the chemically aggressive deep-sea environment. These adverse conditions greatly reduce the choice of construction materials. Moreover, deployment and maintenance operations, employing surface vessels and manned or remotely-operated deep-sea submersibles, are expensive and weather-dependent, thus maximizing the need for high operational reliability.

2. DETECTION PRINCIPLE

When a neutrino interacts in the detector volume or in its vicinity, it can produce a subatomic particle called a muon (See figure 1), which travels across the detector at speed greater than the speed of light *in water*. Such a particle generates a faint blue luminescence called Cherenkov radiation. The principal elements of a neutrino telescope are therefore the sensitive optical detectors, usually photomultiplier tubes (PMTs), which collect this light and transform it into electronic signals. The arrival times of the light collected by optical detectors disposed in a three dimensional array can be used to reconstruct the muon trajectory, and consequently that of the neutrino, which is strongly correlated (See Figure 1).

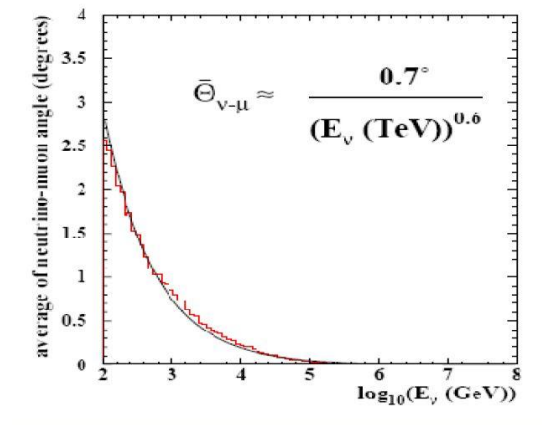
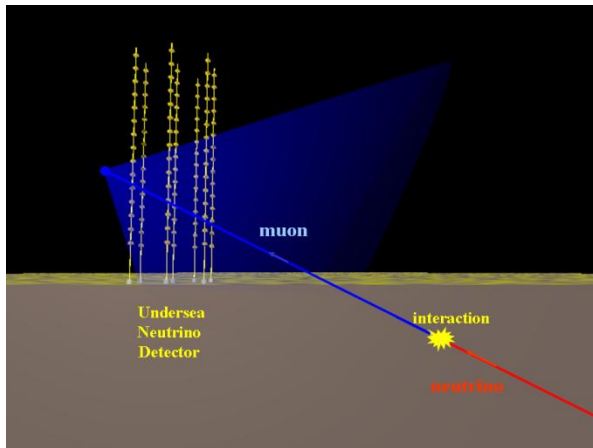


Figure 1. Principle of detection of high energy neutrinos in a deep-sea neutrino telescope (L).

Average angle between muon and neutrino track as a function of neutrino energy (R).

The accuracy of reconstruction of the muon track depends on the precision in measurement of light arrival time and on precise knowledge of the positions of the optical detectors. Good time and position calibration of the detector is therefore of utmost importance to achieve a good angular resolution.

The measurement of the amount of collected light can be fruitfully used to eliminate background events, to improve the muon track reconstruction quality and to estimate the neutrino energy.

3. PILOT PROJECTS

There are currently three ongoing projects for a neutrino telescope in the Mediterranean Sea, ANTARES [3,4,5], NEMO [6,7] and NESTOR [8,9].

The construction of the ANTARES neutrino telescope (See Figure 2) at 2500 m depth off the French Mediterranean coast near Toulon was completed in May 2008. It consists of 12 flexible detection lines, each carrying 75 optical detectors arranged on 25 'storeys' at heights ranging between 100 and 450 m above the sea floor. Lines are anchored to the sea bed on a 70 m grid spacing, and are kept in tension by syntactic foam buoys.

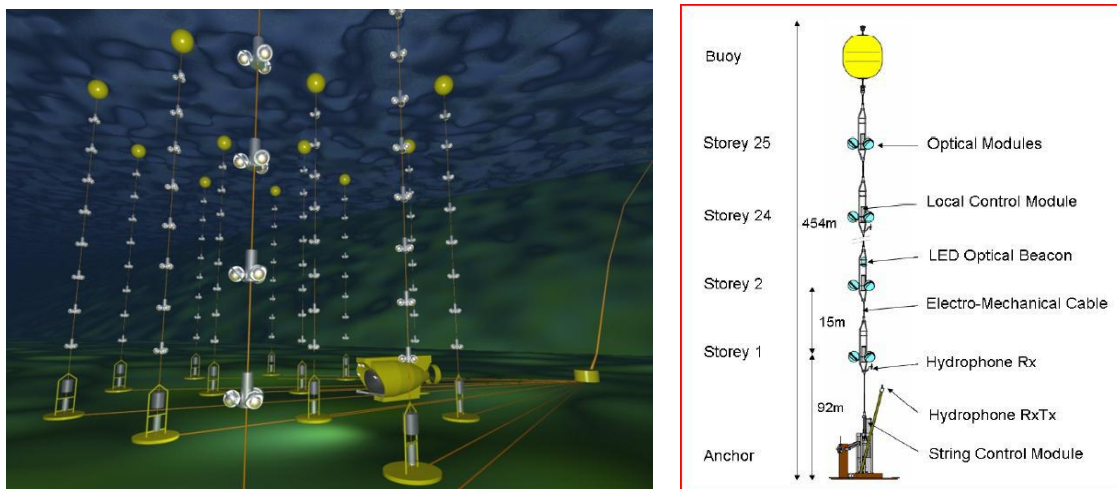


Figure 2: Artist's impression of the ANTARES underwater neutrino detector array (L) and a schematic view of an ANTARES line (R).

An electro-optical link cable connects each line to a sea-floor junction box, which is connected to the shore station through a 43 km electro-optical cable containing 48 optical fibres. The cables linking the lines to the junction box are fitted with electro-optical wet-mateable connectors, requiring a submarine intervention for each connection. Presently the detector is fully operational and some of its elements have been taking data regularly for more than 5 years.

The NESTOR collaboration is constructing a neutrino telescope off the Greek coast near Pylos at a depth exceeding 3000 m. There are different plateaux on the seabed in this region at depth ranging from 3000 to 5200 m. The telescope geometry is a ‘tower’ of 12 ‘floors’; 30 m rigid titanium hexagonal star-like structures each holding six pairs of optical detectors at their vertices and having a titanium sphere at the centre for readout electronics (See Figure 3).

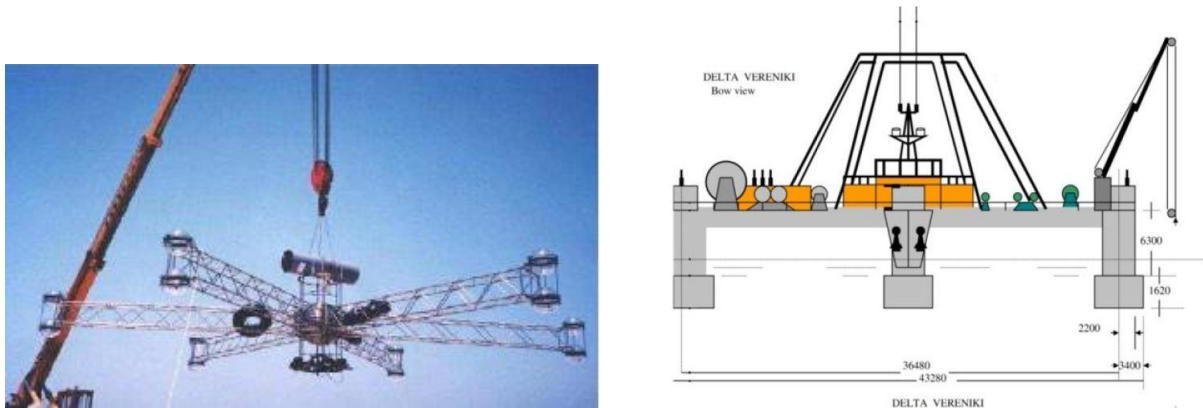


Figure 3. Prototype NESTOR ‘floor’ during preparation for deployment (L) and bow view of the Delta Berenike deployment platform and support vessel (R).

The floors will be stacked with 30 m vertical spacing. To deploy a new floor, the already-deployed partial tower will be lifted to the surface, connected to the new floor and redeployed. In this way connections are made in on-deck operations, without the need for wet-mateable connectors, manned submersibles or remotely operated vehicles. A single floor has already been deployed at 3800 m depth, connected to the shore station and operated for more than one month, confirming the expected performances. The deployment and successive recovery of such large structures are not easy tasks for vessels commonly

used by telecommunication and off-shore oil industry. A dedicated platform vessel can provide an easier access to the sea surface through a central well with crane coverage. Moreover such a vessel would be less affected by rocking, pitching and rolling motion, also allowing operations in less favourable sea conditions. Following the above considerations the NESTOR collaboration has successfully launched a triangularly shaped deployment platform (51 m long, 44 m wide) (See Figure 3) capable of operating at sea state 4.

In addition to this work, members of the NESTOR collaboration are also evaluating components for 100 m diameter star structures within the KM3NeT effort.

NEMO is an Italian R&D project to study the feasibility of a kilometre cube neutrino telescope and possible new solutions for detector components and structures. The NEMO collaboration has performed measurements of water properties and deployment tests at a new possible deployment site at 3300m depth 80 km East of Capo Passero on the Sicilian coast.

NEMO Phase 1 [10], carried out in the period 2004-2007, has allowed the validation of examples of all the components of a future cubic kilometre-scale detector at a test site at 2100 m depth in the bay of Catania. Following the deployment of the 28 km electro optical shore cable and junction box in December 2006 an innovative, unfurling four-storey tower equipped with optical detectors was deployed (See Figure 4) and has acquired data continuously for around six months. Full size towers will contain 16 storeys, each consisting of 20 m rigid arms carrying four optical detectors. Storeys are interconnected by ropes which form a tetrahedral structure sustaining successive arms orthogonally at 40 m vertical spacing when the tower structure is tensioned by its buoy.

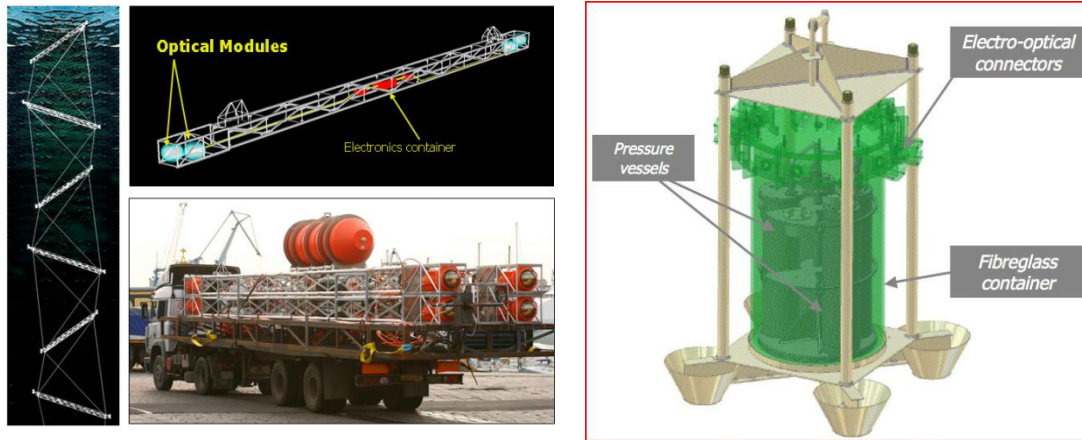


Figure 4. Elements of a NEMO unfurling tower (L) and NEMO junction box (R).

The main advantage of this design is that the tower can be folded in a very compact structure for transportation and deployment and unfurled by the acoustic release of its flotation buoy once anchored to the sea bed.

The NEMO phase 2 foresees the deployment of a full tower at Capo Passero site. The 100 km electro optical cable connecting the onshore station to the detector site has been already deployed while the deployment and connection of the full tower is foreseen by the end of 2008. The completion of phase 2 will allow a new test of the deployment and connection of the innovative self-unfurling tower and its operation at a depth more suitable for the cubic kilometre detector. Moreover a long term continuous monitoring of the site properties (water transparency, optical background, water current, etc.) will be performed.

Another interesting development by the NEMO collaboration is a “hybrid” junction-box, having a stainless steel vessel housed in a composite tank filled with oil (See Figure 4). In this way the steel vessel sustains the pressure while the tank protects it against corrosion. An expensive titanium pressure vessel can be avoided with this solution. The NEMO collaboration and KM3NeT consortium have also verified that many electronic components - various off-the-shelf types of integrated circuits including microprocessors, together with discrete electronic components and electric motors - can operate routinely and reliably under high pressure [11]. Such components can be placed in the dielectric oil between the external tank and the internal pressure tank reducing the needed volume and cost of the steel vessel, or can even be

immersed in thin-wall oil-filled containers made in shapes that would otherwise normally crush if not operated in equipressure.

4. TOWARD A KM3NET DETECTOR ARCHITECTURE

The current submarine neutrino telescopes are all based on structures anchored to the sea bed and tensioned by buoys. Architectures based on variations on these structures are under evaluation for KM3NeT [12]. The elongated nature of these anchored structures means that their upper elements are subject to large movements in undersea currents. Since accurate knowledge (to around 10 cm) of the positions of optical modules is necessary for accurate reconstruction of muon trajectories, a positioning system based on acoustic triangulation is foreseen (section 7).

The completed telescope may contain as many as a hundred detection towers or lines. Redundancy must be built into the powering and dataflow from these elements to the shore cable. Primary and secondary junction boxes may be linked in redundant ring and star paths (See Figure 5) to increase tolerance to faults in sea floor interconnection cables.

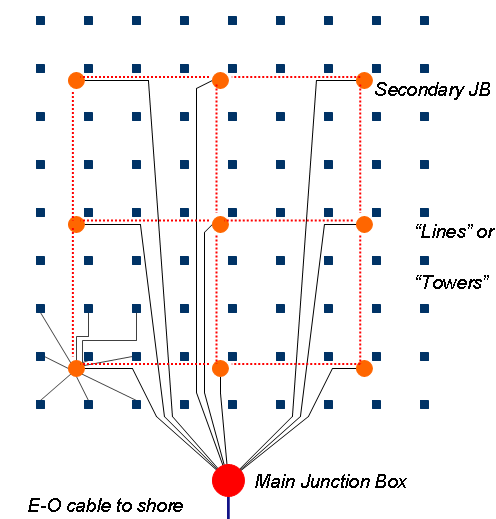


Figure 5. A possible redundant data/power cabling layout.

The cubic kilometre neutrino telescope platform will consist of about 10000 optical detectors with the related electronics plus other electronic equipment for calibration purposes, environmental monitoring and for the associated oceanographic sciences that will share the telescope platform. The overall electrical power needed will be around 50 kW. Considering the power required and the distances over which it must be delivered the use of high voltage is unavoidable. Several schemes for powering the telescope through the 20-100 km shore link cable are under study. These include the transmission of direct current and also single phase [13] or three phase [14] AC. DC is commonly used on long-haul undersea telecommunication cables. Nevertheless the final choice will depend heavily on the selected site since for relatively short distances between the telescope site and the on-shore station high voltage AC powering can be envisaged. An AC power system would allow for the use of transformers instead of expensive DC-DC converters. For distances longer than about 50 km the power loss due to cable capacitance would render AC powering unfeasible.

Suitable electro-optical cables and connectors are readily available on the market and are commonly used in telecommunications and connections in the off-shore oil industry. Although these cables have proven to be highly reliable over long periods of time (more than 25 years) too rigid a compliance with industrial standards might impose too stringent constraints on detector design parameters. Since the shore cable lengths are short compared to typical telecommunication runs, and therefore probably unrepeated, custom cables can be considered, either using multiple power conductors or a single power conductor with a deep sea return electrode for DC powering or single phase AC, as used in ANTARES [15] (See Figure 6). Monopolar cables are generally smaller and lighter than multipolar ones. Moreover, due to the extremely small resistance in the sea return, power delivery through monopolar cables can significantly reduce power losses. A possible problem with this kind of powering is the production of chlorine gas in electrochemical reactions at the return electrodes, which might corrode nearby metallic structures. In bipolar power delivery, a return conductor is required. This can be incorporated in the electro-optical cable delivering the power, or in a dedicated return cable. The main electro-optical cable will run from the on-shore station to the main junction box in the deep sea. The junction box will then be linked via other electro-optical cables (or separated electrical and optical links) to secondary junction boxes connected to telescope detector units and associated sciences nodes.

On site power distribution may use transformers mounted inside junction boxes or DC-DC conversion in a technique similar to that proposed for the Neptune undersea network [16].



Figure 6. Example showing different armoring of a polyethylene-insulated sub sea telecommunication cable with a single electrical conductor and stainless steel tube containing optical fibres. [Photo courtesy of Alcatel Submarine Networks].

Photomultiplier signals due to Cherenkov photons must be extracted from the much more frequent background signals, transferred to the shore station and stored. Analogue sampling transmission is probably impractical as the original signals would deteriorate too severely over the long (up to 100 km) path to the shore station. Therefore the signals will probably have to be digitized in-situ, recording at least the amplitude of the signal and its arrival time. The experience gained with the pilot projects teaches us that to maximise the reliability of the detector the off-shore equipment has to be reduced to the necessary minimum. In this way many points of possible failure are placed on-shore where maintenance operations are much cheaper and less time consuming. Following this approach only a very basic filtering of events will be performed off-shore. No in-water triggering electronics involving signals from more than one optical module is foreseen. All PMT signals whose amplitude is above a certain settable threshold will be sent to

the shore station. The rate of such signals depends on the threshold value chosen and the background level, which in turn depends on the detector site. According to ANTARES experience this rate is around 70 kHz for a 25 cm diameter PMT with electronics set to a 0.3 photoelectron threshold (when bioluminescence activity is low this rate is dominated by the Cherenkov light produced following the decay of the Potassium 40 isotope present in sea salt). Under typical bioluminescence conditions the contributions from the optical modules on detector line will add up to about 1 GB/s, while the overall data flow to shore from a cubic-kilometre scale neutrino telescope with around 100 lines will be around 100 GB/s.

Data transmission over the long distances from the telescope to the shore will be fibre-optic, and may use Dense Wavelength Division Multiplexing (as for example in ANTARES, but with a wider colour palette). Data streams from groups of optical detectors would be superimposed as different colours onto the same optical fibre, with laser drivers probably located in the main junction box. An alternative 10 GB/sec fibre-optic transmission scheme under consideration might combine shore station laser/detectors with interferometric or electro-absorption optical modulators located directly in electronics of the optical modules.

Copper twisted pair is being considered for data transmission over the shorter distances within the telescope. Data speeds up to 100 Mbits/sec for each optical detector would be possible with readout operating under VDSL2¹ over a dedicated twisted pair with a maximum descent distance of 500 m [17]. Lower bandwidth data transmission over copper twisted pair is used in the IceCube under-ice neutrino telescope at the South Pole [18].

Transmission across the seabed from line bases to junction boxes might be over copper or optical fibre. If transmission distances did not exceed typical descent distances, copper twisted pair would be attractive, allowing hybrid (electro-optic) deep-sea mateable connectors to be replaced with simpler 'single-technology' types. Data reforming would however be necessary in dedicated electronics at the 'halfway' points at the bases of the detection lines.

¹ Very high speed Digital Subscriber Line 2, standardized as ITU G 993.2

5. CONNECTIVITY FOR STAGED CONSTRUCTION

The sub-detectors of the KM3NeT neutrino telescope will be deployed in stages requiring data and power connection with the main electro-optical shore cable. Several connection options are being considered.

One option relies on interconnection cables equipped with deep-sea mateable connectors to link the bases of detection lines to junction boxes, and requires the use of a work-class submarine vehicle.

In another option, each ‘telescope element’ (a detection line or a junction box) is equipped with one or more acoustically releasable cable pigtails long enough to reach the sea surface. On-deck connections to each subsequent element can be made, in star or daisy-chain configurations, with inexpensive dry connectors and without the use of submarine vehicles. The drawback of this approach is that as the number of connected sub-detector grows, so does the number of very long cables lying on the sea floor, increasing the risk of damage in later operations.

In an option used by NESTOR, previously deployed telescope subassemblies are recovered and progressively extended in on-deck ship operations. This option requires an anchored buoyant ‘recovery rope’ that can be acoustically released and then used to winch the subassemblies to the surface. In this option, the sea floor cable linking the subassemblies to the main junction box, or a length of the shore cable equal to at least the water depth must be capable of resisting repeated lifts.

6. OPTICAL DETECTION FOR NEUTRINO DIRECTION FINDING

The neutrino telescopes currently in operation all use variants of large format (25 cm diameter and above) hemispherical PMTs as the optical modules (OMs) for muon track finding. These photon sensors are housed in 43 cm diameter glass spheres resistant to high hydrostatic pressures, transparent to photons in the wavelength range 350-500 nm and equipped with watertight and pressure resistant connectors.

The PMTs are coupled to one of the two hemispheres with an optical gel having very good light transmission properties and a refractive index as close as possible to that of the glass sphere, the PMT glass window and the sea water. This gel provides moreover a mechanical coupling sufficiently elastic to absorb possible shocks and vibrations during transportation and deployment as well as the unavoidable deformation of the glass sphere during the deployment.

To reduce the effect of geomagnetic field PMTs are shielded by a mu-metal wire cage designed to minimise shadowing effect on the photocathode.

Figure 7 shows a schematic 3D view of a typical optical module and a complete optical module.

The glass sphere also houses the high voltage generator for the PMT and in some cases the signal integration and digitizing electronics.

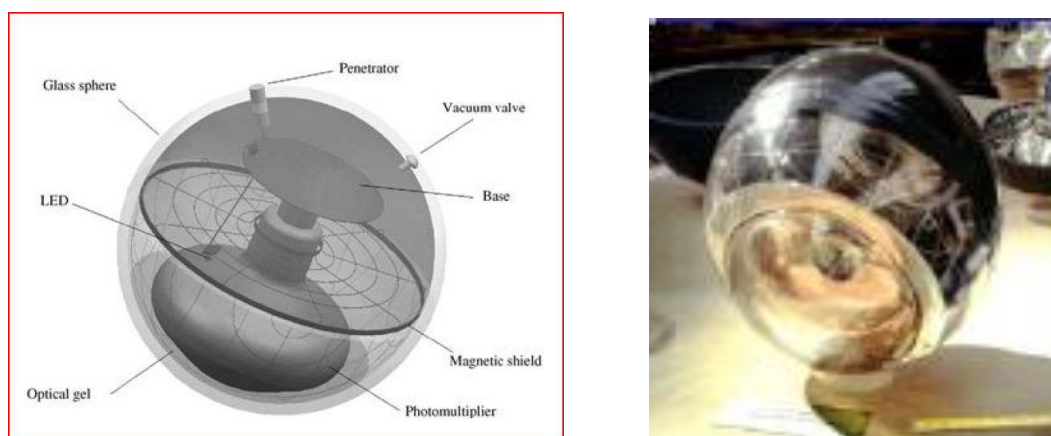


Figure 7. Schematic view of an optical module (L).

Photomultiplier integrated into a glass pressure sphere (R).

The optical module design described above is a natural candidate for the production of KM3NeT optical modules because it has proven to be reliable and work effectively without any need for maintenance over long periods. In particular the optical modules of the first line of ANTARES detector have been working without problems since 2005.

Nevertheless other possible designs exploiting recent technological developments are under investigation to reduce the rate of background events due to K^{40} decay and bioluminescence, and also to improve the cost effectiveness. In addition to 'conventional', single channel PMTs, hemispherical four

channel PMTs [19] and higher performance hybrid PMTs with an intermediate crystal scintillator [20,21] are being considered for KM3NeT.

Standard hemispherical single anode PMTs cannot provide any information on the direction of detected Cherenkov photons. Replacing such PMTs with segmented-photocathode types coupled to a mirror system would convey additional useful information on the direction of incoming photons (See Figure 8). Background photons could be more effectively rejected checking the compatibility of their direction with that of the reconstructed muon track. Moreover the knowledge of Cherenkov photon trajectories would improve the track reconstruction and consequently the angular resolution, especially at low energies when the number of hit PMTs is very small.

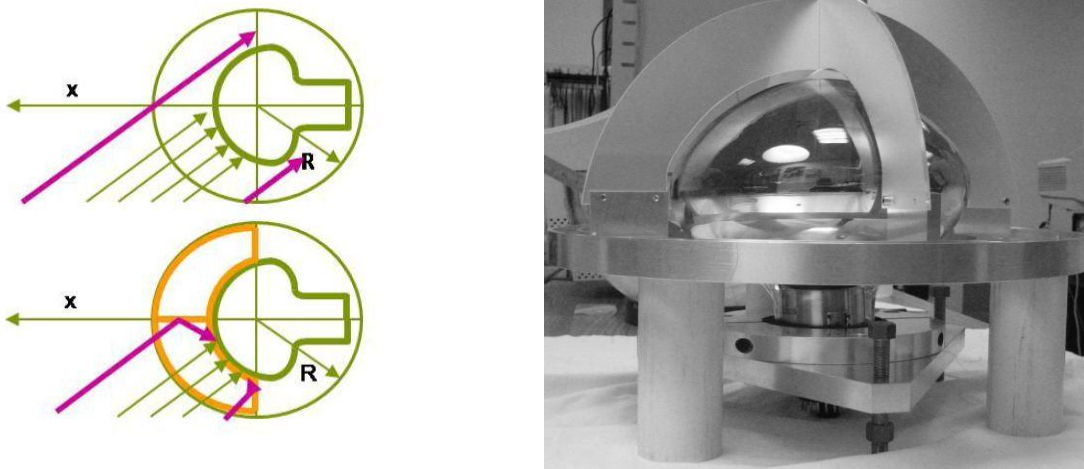


Figure 8. Schematic view of an OM with a standard hemispherical PMT (upper left) and of an OM with a segmented photocathode PMT coupled to a mirror system (lower left). Prototype before the integration in a glass sphere (right).

Scintillating hybrid photon detectors (X-HPDs) have been already used for a long time by the Lake Baikal neutrino telescope, proving their reliability. In this kind of detector photoelectrons emitted by the photocathode are accelerated toward a scintillating crystal target located at the centre of the device. When the accelerating voltage is high enough, 25 – 30 kV, the crystal emits scintillation light which can be detected by a conventional small phototube. The large photon amplification provided by the scintillating

crystal, ranging between 20 and 50, results in an improved pulse resolution. These detectors show some other very interesting properties like larger solid angle coverage than standard hemispherical photomultipliers, better photoelectron collection efficiency and higher effective photo-conversion efficiency. Thanks to the higher accelerating voltage no screening against the geomagnetic field is needed. Moreover, due to the relatively radial motion of the accelerated photons the transit time spread is small - less than 1 nanosecond - assuring good timing capabilities. Considerable improvements in terms of angular acceptance, photo-conversion efficiency and transit time spread can be achieved with a true spherical geometry. Members of the KM3NeT collaboration are pursuing the development of truly spherical X-HPD. Some prototypes have been already produced in collaboration with CERN and Photonis S.A.S. and are presently being characterized. Preliminary measurements have confirmed many of their attractive features.

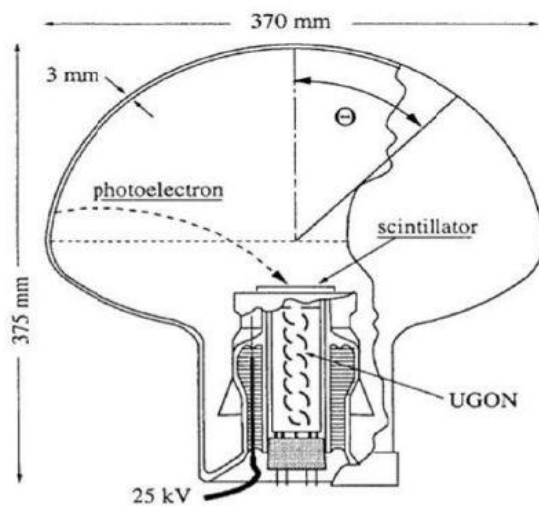


Figure 9. The Quasar 370 X-HPD used by the Lake Baikal neutrino telescope (L).

Prototype of an 20 cm X-HPD with spherical geometry (Courtesy of CERN) (R).

Another option is the equidistant placement of a number of smaller, cheaper PMTs (See Figure 10) [22]. To reduce cost, all the PMTs in the sphere would share the same high voltage. Up to 30 7.5 cm

PMTs can be installed in a single 43 cm OM pressure sphere. The overall photocathode surface would be 15% larger than that of a similarly-sized OM with 3 25 cm photomultipliers and would have a lower cost. Since each PMT would receive fewer background photons, aging would be slower, resulting in more stable long term gain. Small PMTs do not require mu-metal shielding against the geomagnetic field and are already available with enhanced quantum efficiency (about 30 % at 400 nm) and a nearly perfect photoelectron collection.

The read-out of every PMT would proportionally increase the number of electronic channels and the total cost. A possible solution is the digitalization of the 'WIRE OR' of the individual PMT outputs, with a time-over-threshold signal indicating the number of PMTs with signals [23].

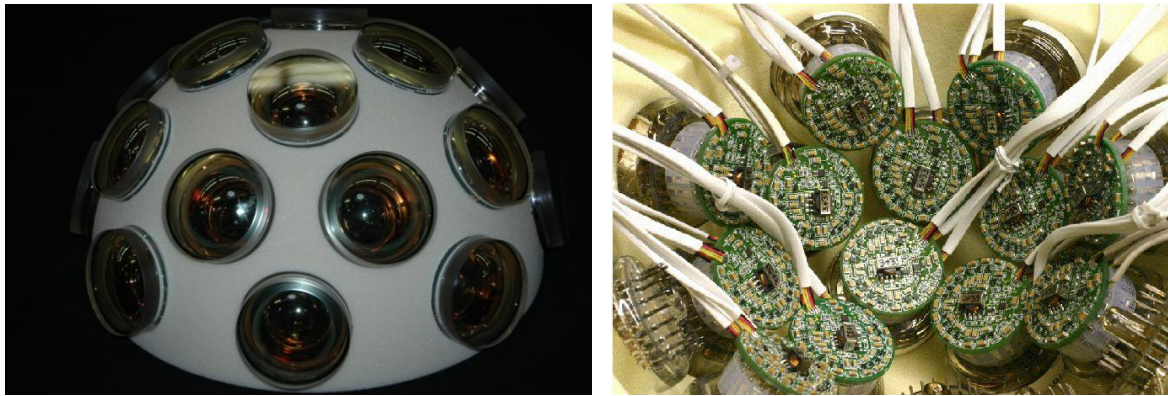


Figure 10. An option for an optical detector sphere with multiple small PMTs (L) and the HV suppliers attached to each photomultiplier tube inside the sphere (R).

7. TIMING AND POSITION CALIBRATION

The optical detectors in a large volume neutrino telescope are at different heights from the sea floor, and correspondingly at different cable lengths from the shore station. Where detection lines are flexible structures anchored to the sea floor and tensioned by buoys, optical detectors are also subject to undersea currents, which can change their positions by several metres relative to a fixed local coordinate system.

For accurate muon tracking, knowledge of the relative timing delays between optical detectors due to different cable lengths is required to a precision of ~ 1 ns. Similarly the positions of the optical detectors must be known to a precision of ~ 10 cm.

The experience gained in previous experiments shows that a relative timing calibration at the 1 ns level can be achieved with two dedicated systems.

The first system uses a shore-based clock to measure the overall time delay in the electronic chain between each optical detector and the shore station by injecting calibration pulses to the readout chain as close as possible to the entry points of signals from the optical detectors. These pulses are returned through the readout chain and the time offsets between various different channels are revealed as half the differences between the corresponding round trip transit times.

The second system uses a triggered array of pulsed light beacons to generate nanosecond-scale flashes which directly illuminate the PMTs through the intervening sea water. Within the framework of the KM3NeT design study, light injection schemes based on pulsed laser beacons emitting very short (a few tens of picoseconds) pulses, and pulsed LED beacons (pulse width ~ 4 ns) are under investigation. A hybrid time calibration system based on laser and LED light beacons is currently used by ANTARES and has proved capable of ~ 0.5 ns relative time calibration accuracy.

Real time determination of the positions of all optical detectors to a precision of ~ 10 cm in the KM3NeT neutrino telescope is being studied [24] using two techniques.

The first technique combines a High Frequency Long Baseline (HFLBL) sea floor acoustic transponder net with hydrophones and tiltmeter-compass sensors at various heights along the detection lines. The 3D position of each hydrophone is determined by acoustic triangulation using transit times of sound pulses received from several transponders. The roll, pitch and compass heading (dependent on line twist) of each optical detector are combined with the hydrophone positions to fit the 3D line shape. A similar system is in use in ANTARES and preliminary results show that the desired ~10 cm resolution on 3D position is achievable.

The second, opto-acoustic technique system uses acoustic triangulation to measure the 3D positions of pulsed light sources (beacons) dispersed throughout the detector. The positions of optical detectors would then be determined by triangulation of light signals from these beacons. The final precision on the 3D position of an optical detector will be given by the convolution of the two triangulation steps.

8. SITE PROPERTIES AND AVAILABILITY AS A DEEP SEA SCIENCE INFRASTRUCTURE.

The deep sea environment presents numerous technical challenges for a neutrino telescope. In addition to high pressure, undersea currents and corrosive potential, the environment presents significant optical backgrounds from the decay of radioactive potassium⁴⁰ present in salt, together with seasonally-varying bioluminescence by sea fauna. The directions of incoming neutrinos must be found by untangling muon trajectories from this background, either 'off-line' at the shore station, implying a high data bandwidth, or through the use of local triggering in which coincidences are demanded between multiple optical detectors to locally reduce the background.

Particulates in sea water can degrade its optical transparency at blue-green wavelengths where the PMTs are most sensitive, and can coat optical surfaces, reducing their transmission.

With these challenges in mind, a series of qualification studies has been performed at the sites of the three pilot projects, and will continue during the three year period of the KM3NeT preparatory phase. These studies involve the long-term (over several months) deployment of sea floor instrument packages

which include 3D current profilers and autonomous DAQ systems for long-term measurements of water transparency, salinity, temperature and bio-deposition rates. Sea floor sedimentation samples have been taken at the three sites.

As part of a general trend in development of global ocean observing systems the ESONET [25] (European Seas Observatory NETwork) programme proposes a chain of cabled observatories to provide strategic long term monitoring capability in geophysics, chemistry, biology, biochemistry and fisheries. The deployment of EMSO (European Multidisciplinary Seafloor Observatories) [26] will provide continuous real time data acquisition and continuous vigilance against hazards such as earthquakes and tsunamis. The three KM3NeT candidate sites, ANTARES in the Ligurian Sea, NEMO and NESTOR in the Ionian Sea are proposed as a basis for the Mediterranean segment of ESONET.

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REFERENCES

- [1] Bagley, P. et al. (2008). "KM3NeT Conceptual Design Report for a Deep-Sea Research Infrastructure Incorporating a Very Large Volume Neutrino Telescope"
KM3NeT CDR available from KM3NeT Consortium web site: <http://www.km3net.org>
- [2] Katz, U.: "Status of the KM3NeT Project" Proceedings of 3rd Workshop on a Very Large Volume neutrino Telescope for the Mediterranean Sea (VLVnT08) Toulon, April 22-24 2008, to be published in Nuclear Instruments and Methods A.
- [3] E. Aslanides et al., [ANTARES Coll.], "Report CPPM-P-1999-02 (astro-ph/9907432)", 1999 ANTARES Coll. "Technical Design Report", 2001, available at <http://antares.in2p3.fr/Publications/TDR/v1r0>

- [4] G. Hallewell on behalf the ANTARES Collaboration, "Construction and operation of the ANTARES underwater neutrino telescope", 6th Workshop on Ring Imaging Cherenkov Detectors, Trieste, Italy, October 16-20 2007, Nuclear Instruments and Methods in Physics Research A **595** (2008) 51-53.
- [5] Circella, M.: "Status of the ANTARES neutrino telescope" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [6] P. Piattelli et al. [NEMO Coll.] Nucl.Phys.Proc.Suppl. **143**, 359 (2005)
- [7] Capone, A.: "Status of the NEMO Project" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [8] P.K.F. Griedner et al. [NESTOR Coll.] Nuovo Cimento **24 C**, 771 (2001)
- [9] Rapidis, P.: "Status of the NESTOR underwater neutrino telescope" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [10] Amore, I.: "Results from the NEMO Phase-1 experiment" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [11] Russo, S.: "Qualification tests and readout electronics reliability analysis for the deep sea underwater telescope NEMO" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [12] Coniglione, R.: "KM3NeT: optimization studies for a km³ neutrino detector" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [13] Concimano, R.: "A comparison of AC and DC power feeding systems based on the NEMO experiences" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [14] R. Cocimano *for the NEMO collaboration* "The NEMO phase-1 power and control systems: Status and test results."; Ibid; Nucl.Instrum & Meth.A567:521-523 (2006)
- [15] M. Anghinolfi et al.: "The deep sea hub of the ANTARES neutrino telescope"; Proc. 2nd Workshop on Very Large Volume Neutrino Telescopes (VLVNT2), Catania, Italy, 8-11 Nov 2005. Published in Nuclear Instruments & Methods A567: 527-530, (2006)
- [16] H. Kirkham "Lessons learned from the NEPTUNE power system, and other deep-sea adventures." Ibid; Nucl.Instrum. & Meth.A567:524-526 (2006)
- [17] Jansweijer, P.: "A low cost redundant store and forward DAQ system for KM3NeT, using copper in the Vertical String" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.

- [18] Resconi, E.: "Status and prospects of IceCube neutrino telescope" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [19] Bersani, A.: "Instrumentation of a New Direction Sensitive Segmented Optical Module" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [20] Hallewell, G.: "Crystal-based hybrid single photon detector development for the KM3NeT cubic kilometre neutrino telescope" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [21] Lubsandorzhev, B.: "Hybrid Phototubes in Neutrino Telescope: Experience and Perspectives" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [22] Lohener, H.: "Sensitivity of a multi-photomultiplier optical module for KM3NeT" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [23] Bourlis, G.: "Time over Threshold electronics for an underwater neutrino telescope" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [24] Ardid, M.: "Positioning System of the ANTARES Neutrino Telescope" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [25] Puillat, I.: "Experience in ESONET NoE and Standardisation issues for undersea observatories" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.
- [26] Favalli, P.: "EMSO: the European Multidisciplinary Seafloor Observation" Proc. of VLVnT08; to be published in Nuclear Instruments and Methods A.

KM3NeT (<http://www.KM3NeT.org/>) is an international consortium of European institutes, including members of the ANTARESNEMO and NESTOR experiments, working on a EU-funded design study and preparatory phase for a cubic kilometre-scale underwater neutrino telescope and platform for deep-sea science.

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